

Self-Cleaning Culverts

From Concept and Laboratory Testing to Field Implementation



Marian Muste
IIHR-Hydrosience & Engineering, The University of Iowa

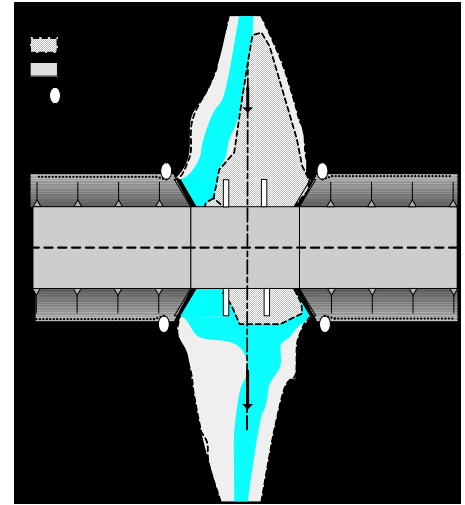
Dave Mulholland
Iowa Department of Transportation

53rd Annual ASCE Environmental and Water Resource Conference, Cedar Rapids, Iowa
March 26, 2015



The Problem

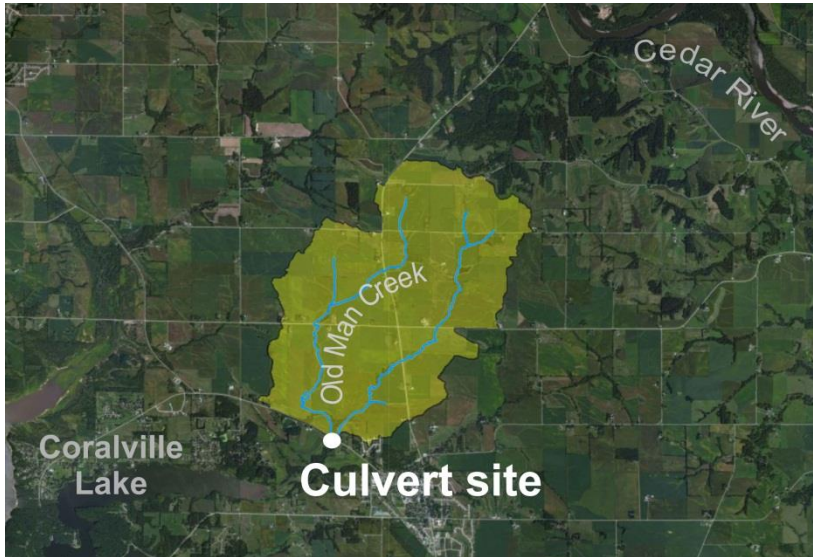
- Typical culverts are designed to handle the 10 to 50-year flows; The concerns about transport of sediment and debris or fish passage are not very detailed
- Multi-box culverts are typically much wider than the natural channel → most of the time, however, multi-box culverts carry the flow through one of the barrels
- The transitions of the stream to and from a multi-box culvert disturb the natural channel regime → sedimentation occurs and develops depending on various general and local factors
- Literature, research and knowledge on this problem is limited and scarce →



Currently, **MECHANICAL CLEANING** is most often
the SOLUTION



Problem illustration



- Old Man Creek culvert: drainage area about 8 mi²

Problem illustration



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- GPS-based survey of the volume of the sediment accumulated in the upstream area of the culvert covers 1033 ft² and occupies 2260 ft³

Problem illustration

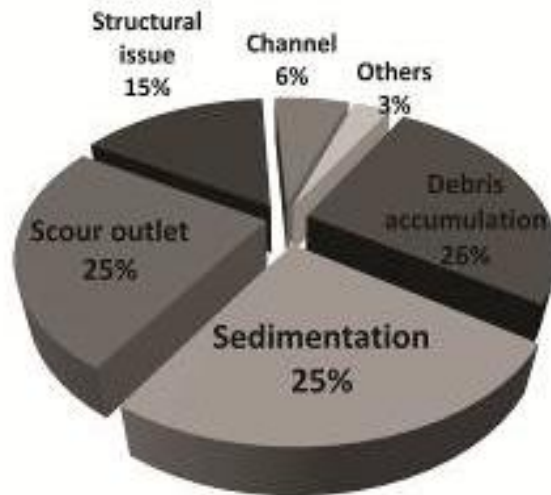


- Old Man Creek culvert: drainage area about 8 mi²
- GPS-based survey of the volume of the sediment accumulated in the upstream area of the culvert covers 1033 ft² and occupies 2260 ft³
- The 5-year sediment buildup after cleanup resulted in 25% reduction of the original culvert conveyance capacity

More information on the problem

- A survey of the personnel in charge with road maintenance (2007) illustrated the chronicity of the problem in Iowa and the lack of efficient solutions for cleanup (excepting mechanical cleaning)

a) Most often encounter problems?



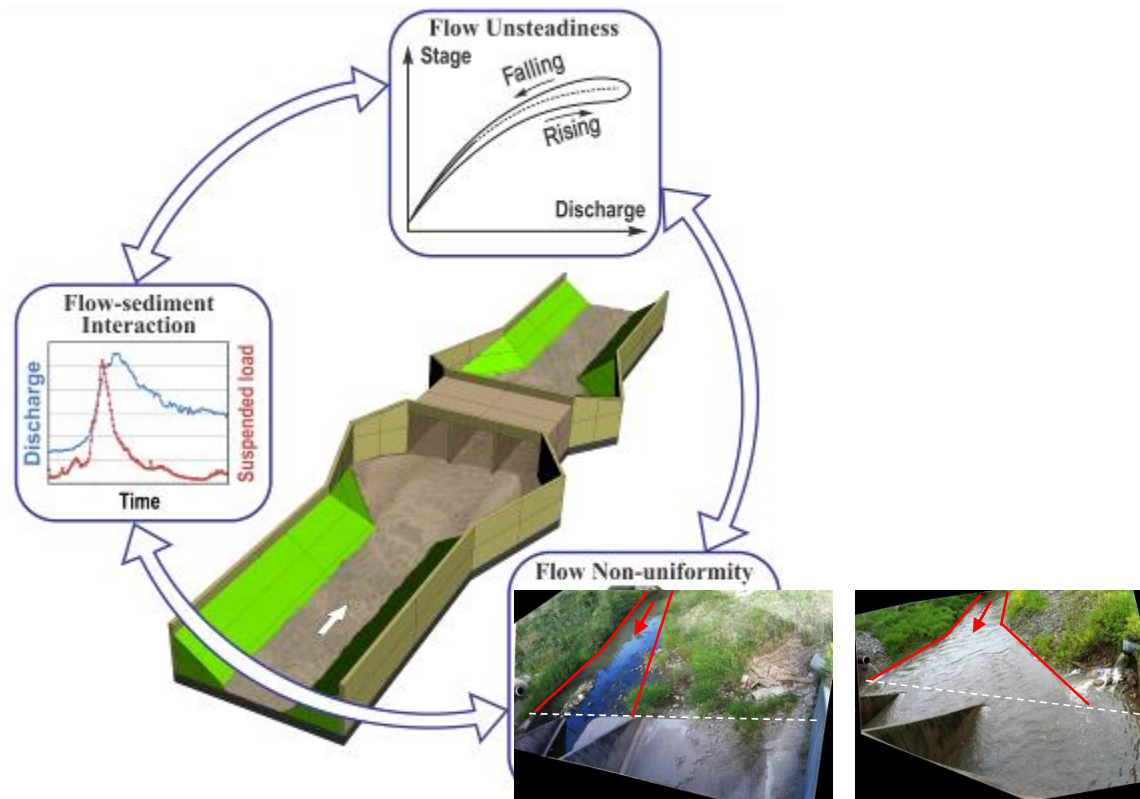
b) Do you have successive experiences regarding mitigation of sedimentation ?



- Project overarching goal: to find an efficient mitigation solution

Searching for solution

- Soon after project start-up, we learned that the problem is not simple to replicate in the lab as the boundary conditions and timing of the process are not well known
 - **Phase 0** (lacking well-documented references on this complex flow we undertook our own investigation on process understanding)



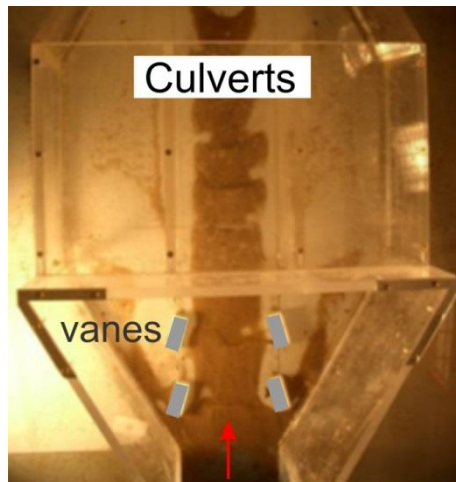
Searching for solution

- Carried out a multi-prong investigative approach:
 - **Phase I**
 - Field investigations
 - Laboratory modeling
 - Companion numerical simulations
 - Search for sediment mitigation concept
 - Laboratory tests for assessing the sediment mitigation solution performance
 - **Phase II**
 - Selecting a site for sediment mitigation solution implementation
 - Monitoring of sediment dynamics in the cleaned culvert (2 years)
 - Construction of the mitigation structure
 - Monitoring the culvert after structure construction (1 year)

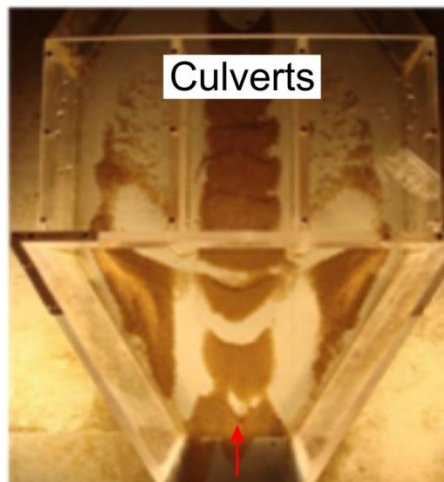
Phase I: Searching for solution

- Concept: self-cleaning
- Hydraulically driven – to not require further maintenance
- Minimum disturbance of the flow hydraulics, sediment transport, and riverine ecology and habitat (i.e., to maintain as much as possible the natural stream operation prior to culvert construction)
- Screened two concepts:

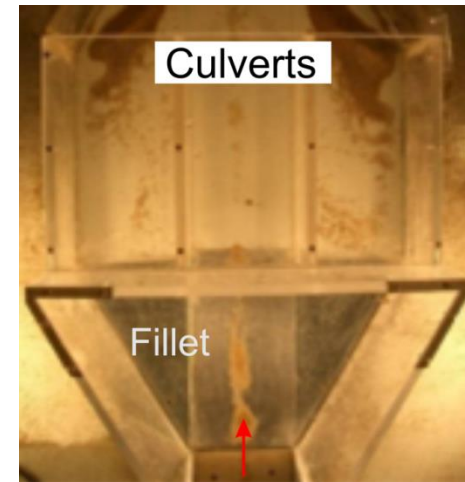
a) vanes



as is



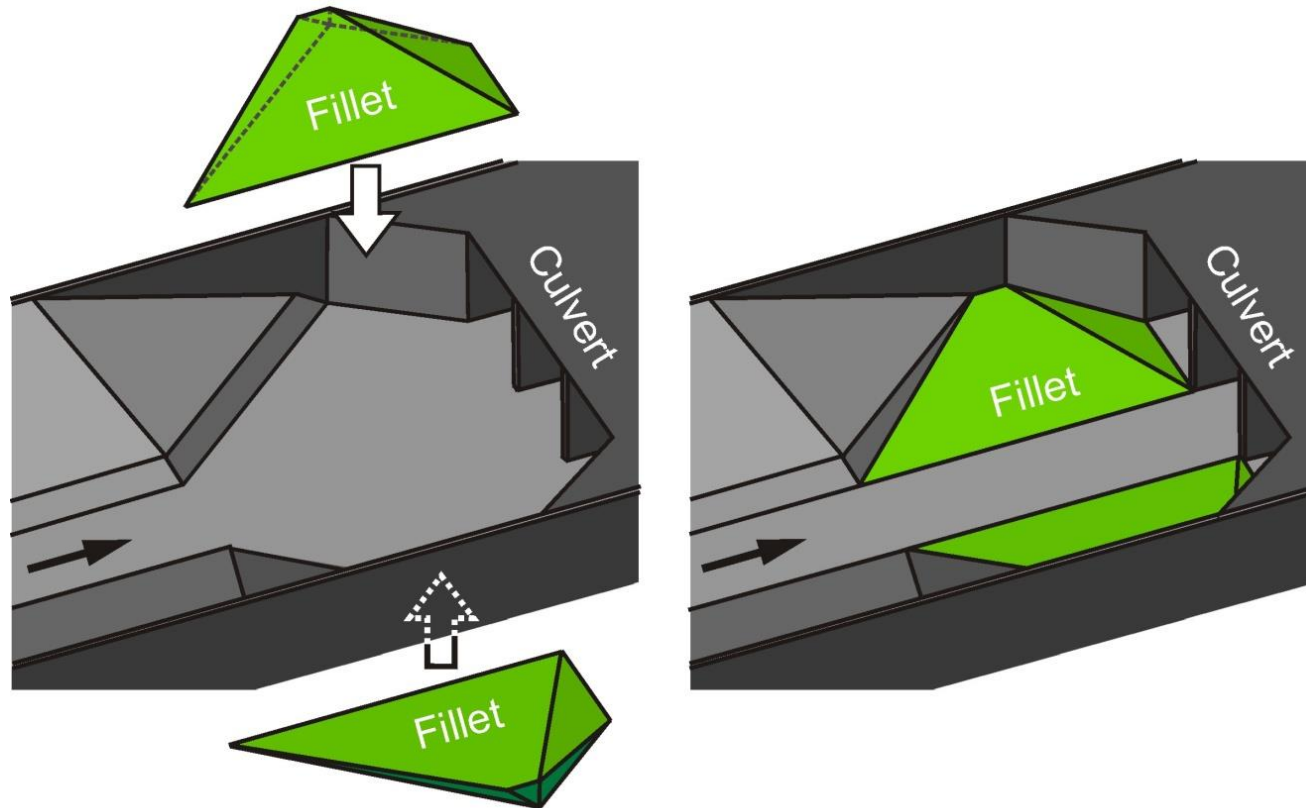
b) fillets



Phase I: Selecting the solution

- Laboratory tests lead to the conclusion that the fillet-based configuration is the more effective adjustment as:
 - While the vane-based design is efficient in terms of sediment routing, the vane presence is problematic for debris passage
 - The fillet-based design avoid the problem of debris accumulation, and maintain the sediment transport close to the conditions of the undisturbed stream
 - Construction of the fillet-based design is more economical (for new and retrofitting existing culverts)

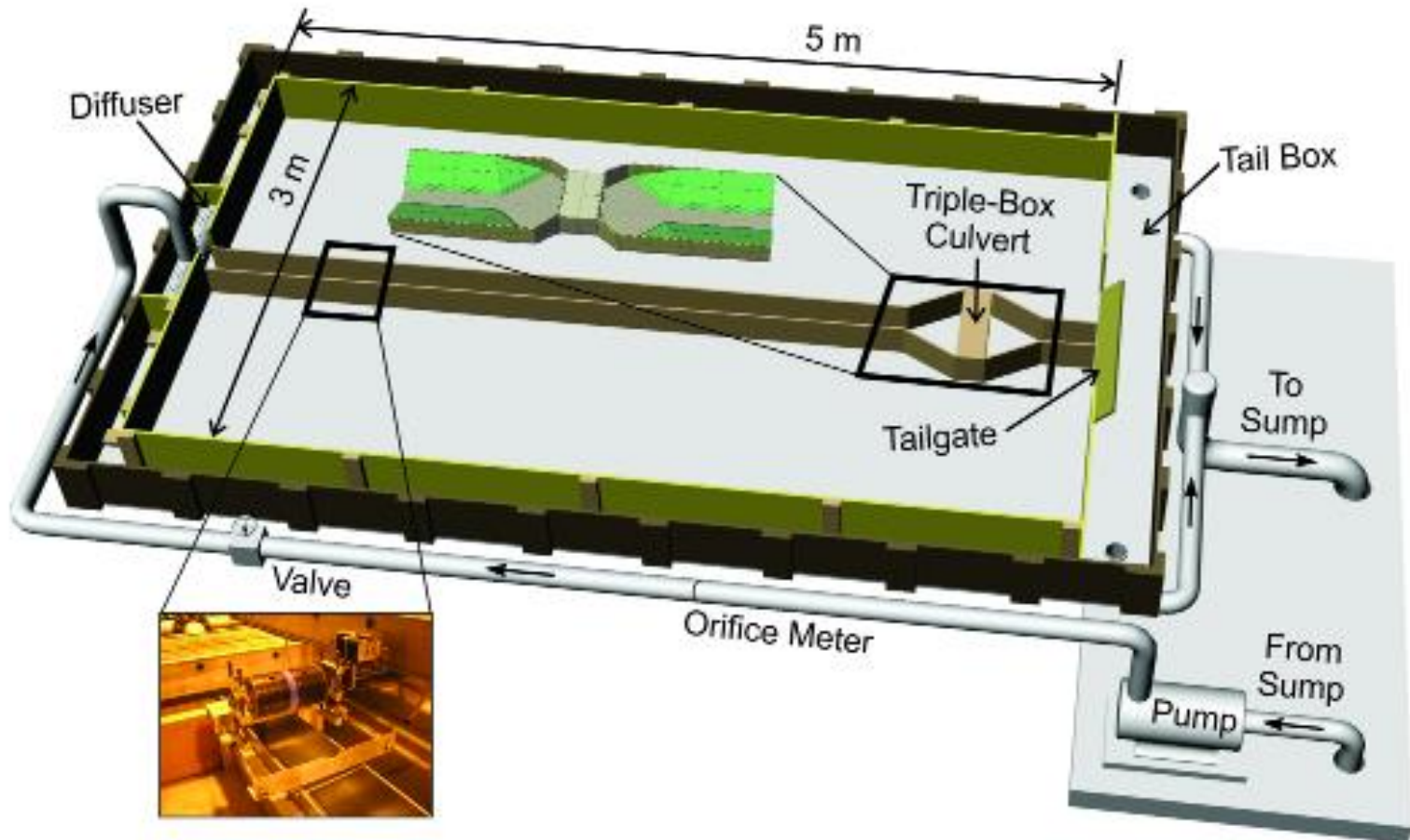
Phase I: Fillet-based design



- Increased flow velocities in the main channel → increased sediment transport capacity
- Enhanced turbulence in the side barrels → keeps the sediment in suspension

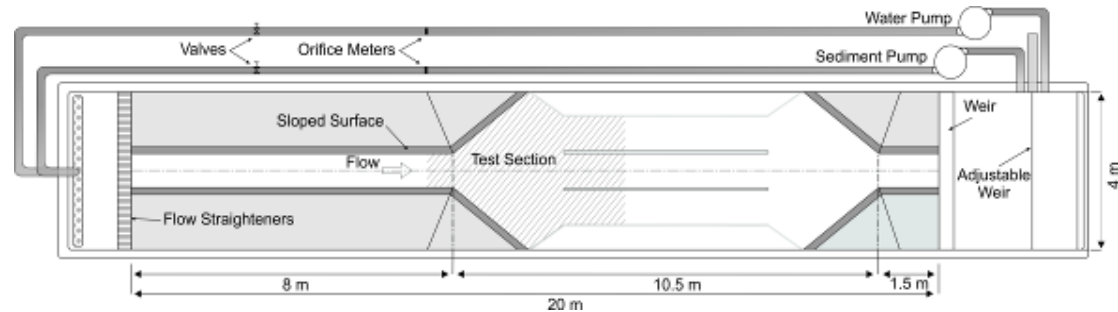
Phase I: Testing the solution

❑ Small-scale model (1:20)

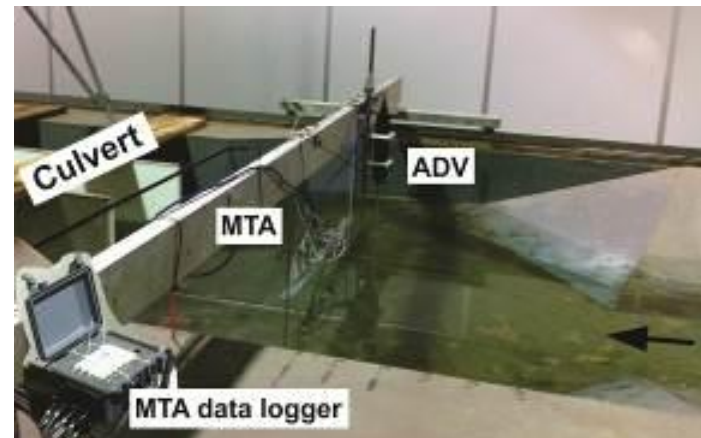


Phase I: Testing the solution

❑ Large-scale model (1:5)



Global measurement

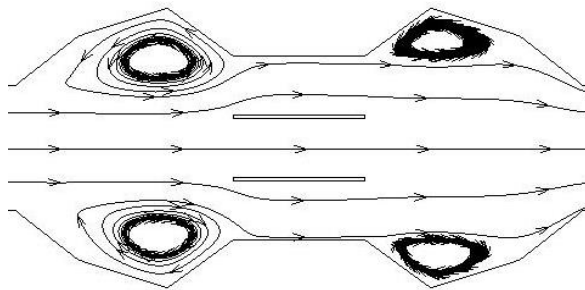


Local measurement

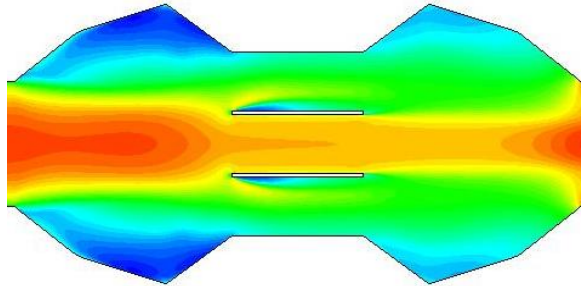
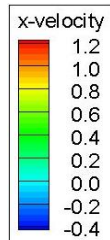
Phase I: Testing the solution

☐ Numerical simulations

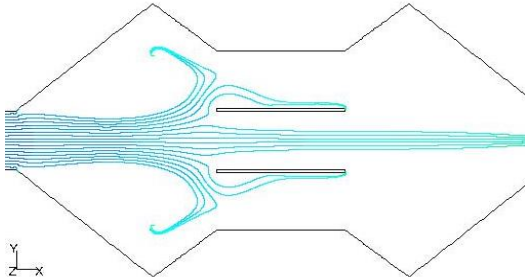
No fillets



Streamlines

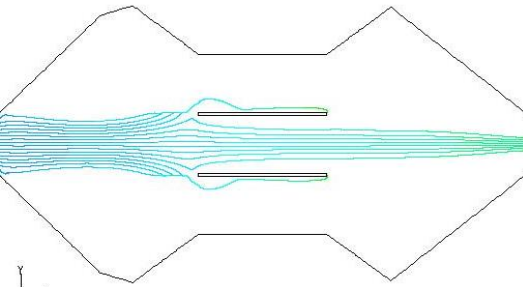
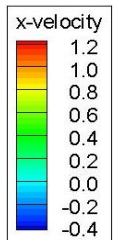
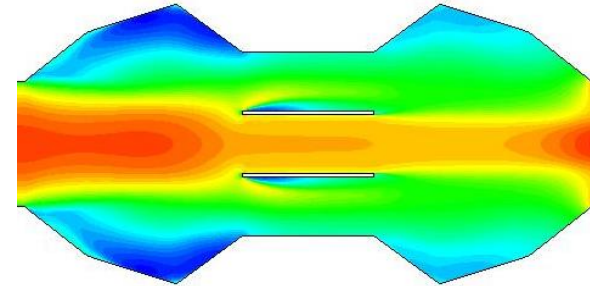
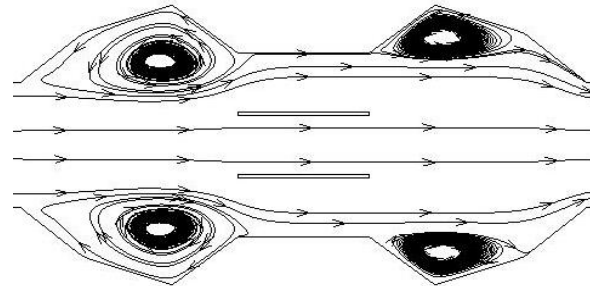


Isovelocity



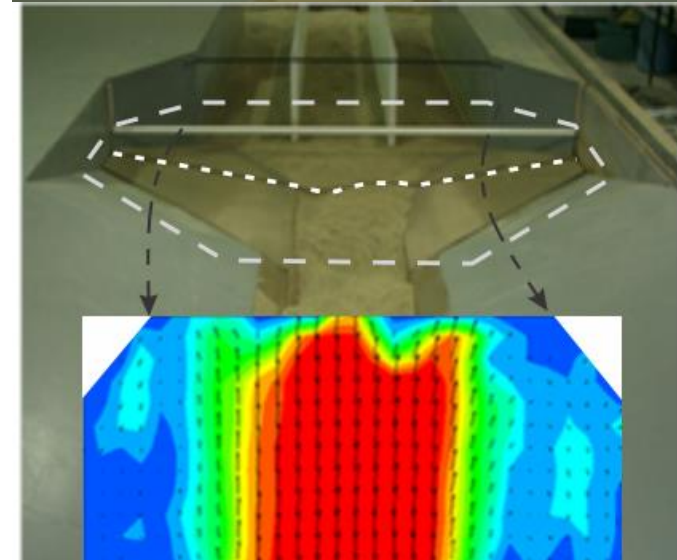
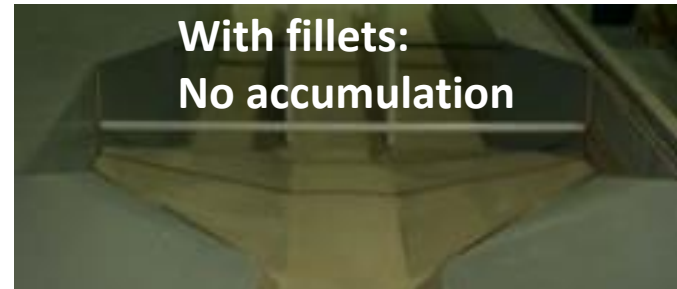
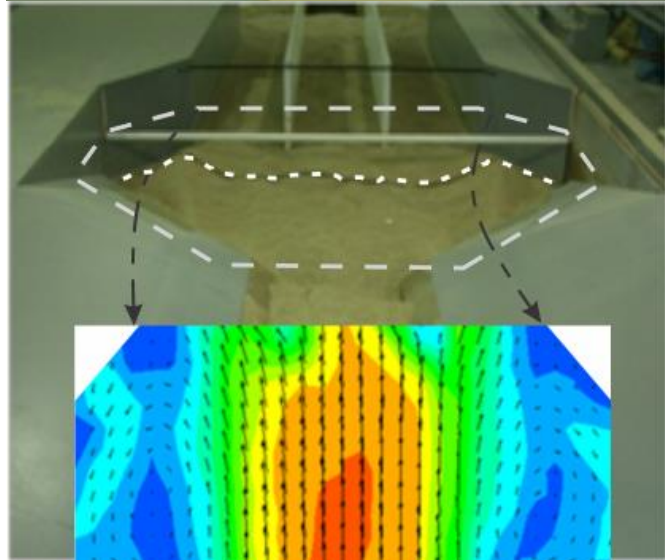
Sediment path

With fillets



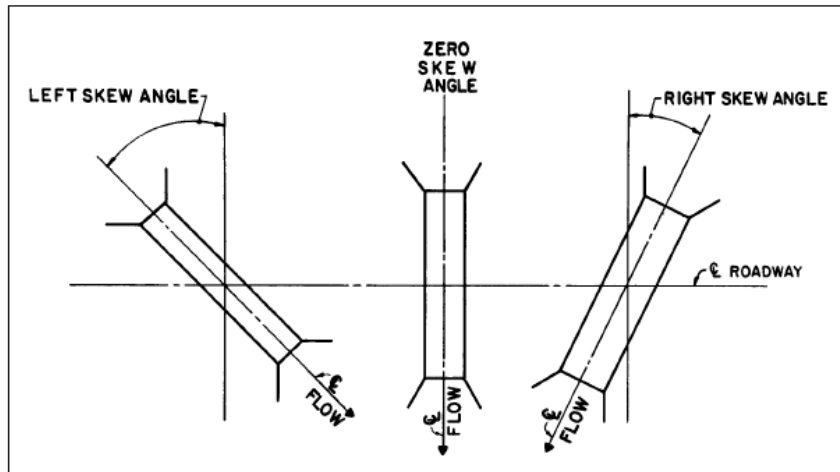
Phase I: Performance tests

❑ Large-scale model (1:5)



Phase I: Performance tests

Sensitivity to various stream-to-culvert angles



- The fillet-based design proved its efficiency for all tested cases
- The actual implementation is site specific and require individual evaluation and design specifications

Phase II: Culvert cleanup

Second cleanup: September 15, 2010 – to support the present study

Before



After



Phase II: Monitoring equipment

Real-time stream stage recording & wireless communication

Solar-powered ultrasonic stage sensor with wireless data transmission



Real-time image recording & wireless communication

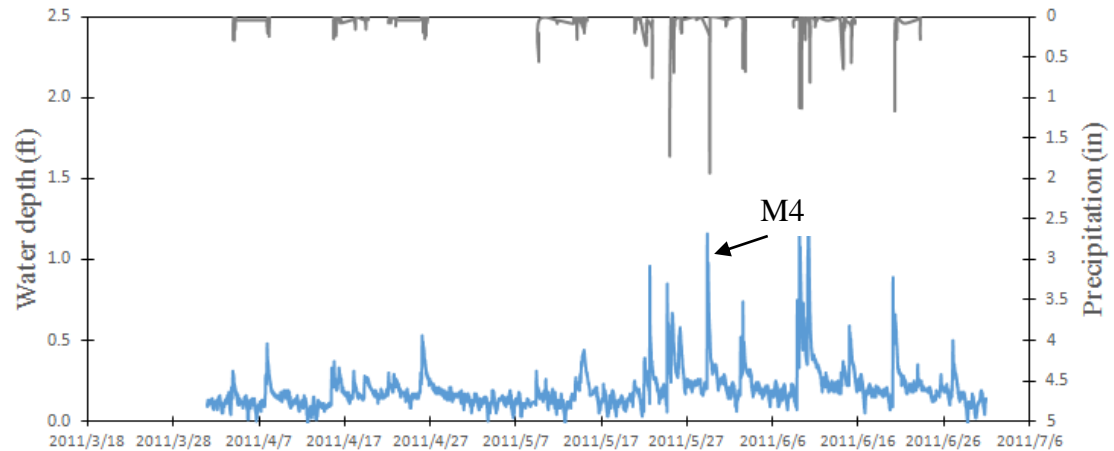


Solar-power digital camera with wireless images transmission to a customized internet site



Phase II: Site monitoring – no fillets

May 29, 2011:
(storm M4) largest
flow event in 2011



Culvert oversized (1.2 ft out of 12 ft height) ?

Phase II: Site monitoring – no fillets

- Webcam image record: Sept 30 – No 22, 2011



Phase II: Site monitoring – no fillets

Right culvert box: deposition evolution after cleanup



1 year



2 years



Phase II: Site monitoring – no fillets

Left culvert box: deposition evolution after cleanup

2 years

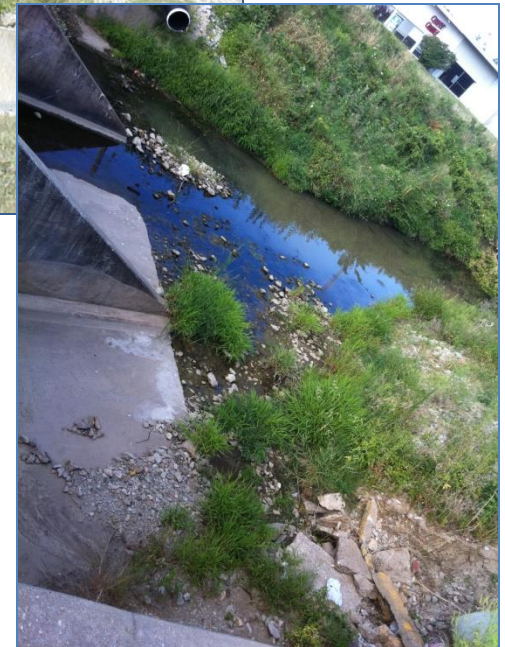


1 year



Phase II: Site monitoring – no fillets

Culvert status following 2 years from the cleaning (August 29, 2012):



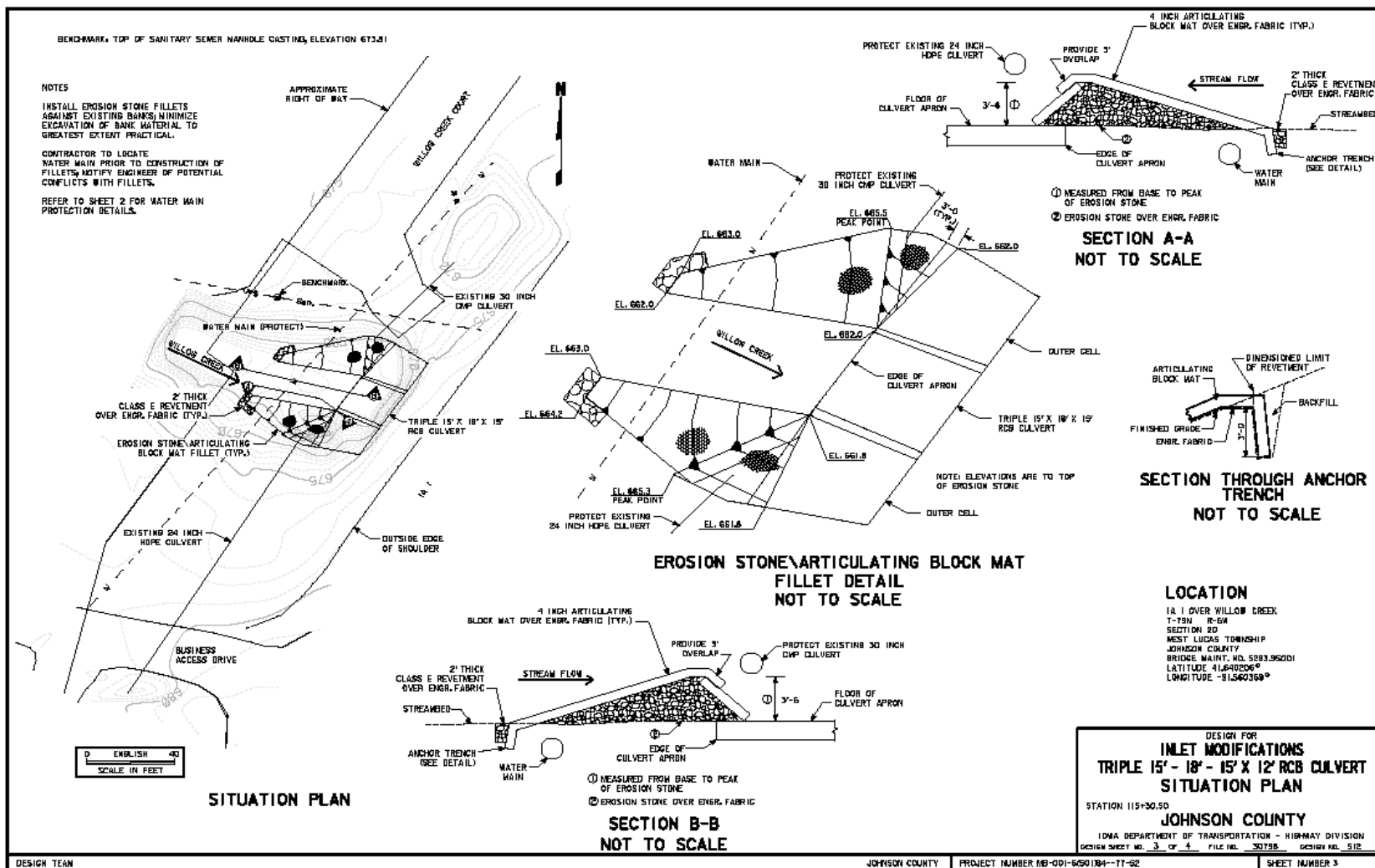
- **sedimentation** upstream the culvert was initiated
- sediment deposits favors **growth of vegetation** during the summer low flows
- encroached vegetation will act as **sediment barrier** in the next season

Phase II: Fillets construction



- **Streamlining** flow over the whole range
- **Enhance turbulence** in the side boxes
- **Suppress deposition** in the side lobes
- **Suppress vegetation growth**
- Can be applied for **new culverts or as a retrofitting measure**
- **Do not affect the culvert design cross-section**



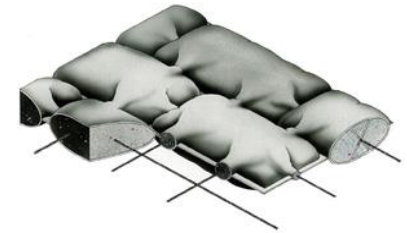


Phase II: Fillets construction

Construction time: December 2012

Fillet material: Articulating Block Mats (ABM) produced by Texicon
(<http://www.texicon.com>)

Contractor: DeLong Construction, Inc, Washington (IA)
Construction Cost: \$24,300



Upstream view



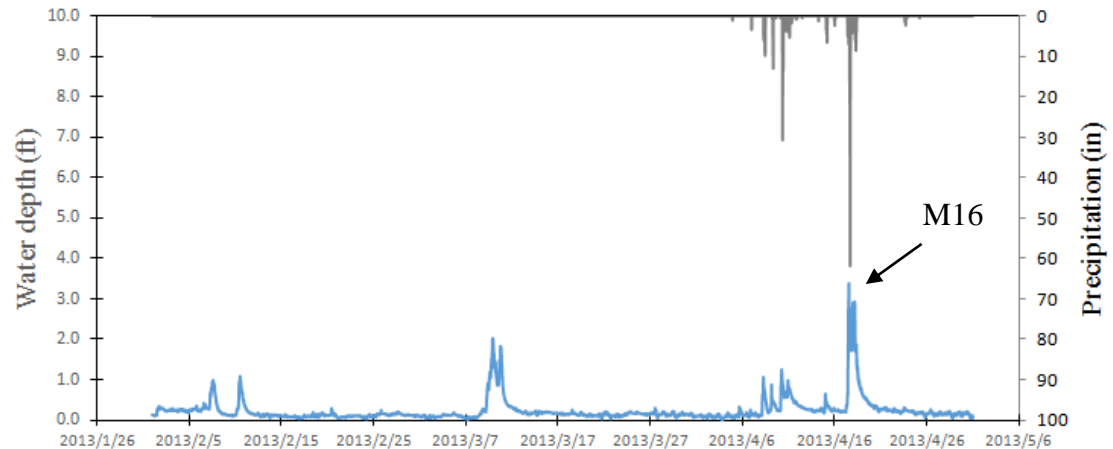
Right barrel

Left barrel



Phase II: Site monitoring – fillets in

April 20, 2013:
(storm M16)
largest flow in
three years of
monitoring
(09/2010-09/2013)



Culvert oversized (3.5 ft out of 12 ft)?

Phase II: Site monitoring – fillets in

- Webcam image record: storm of April 10, 2013



Phase II: Site monitoring – fillets in

- Culvert status at the end of the monitoring (October, 2013)

Right barrel



Central barrel



Left barrel



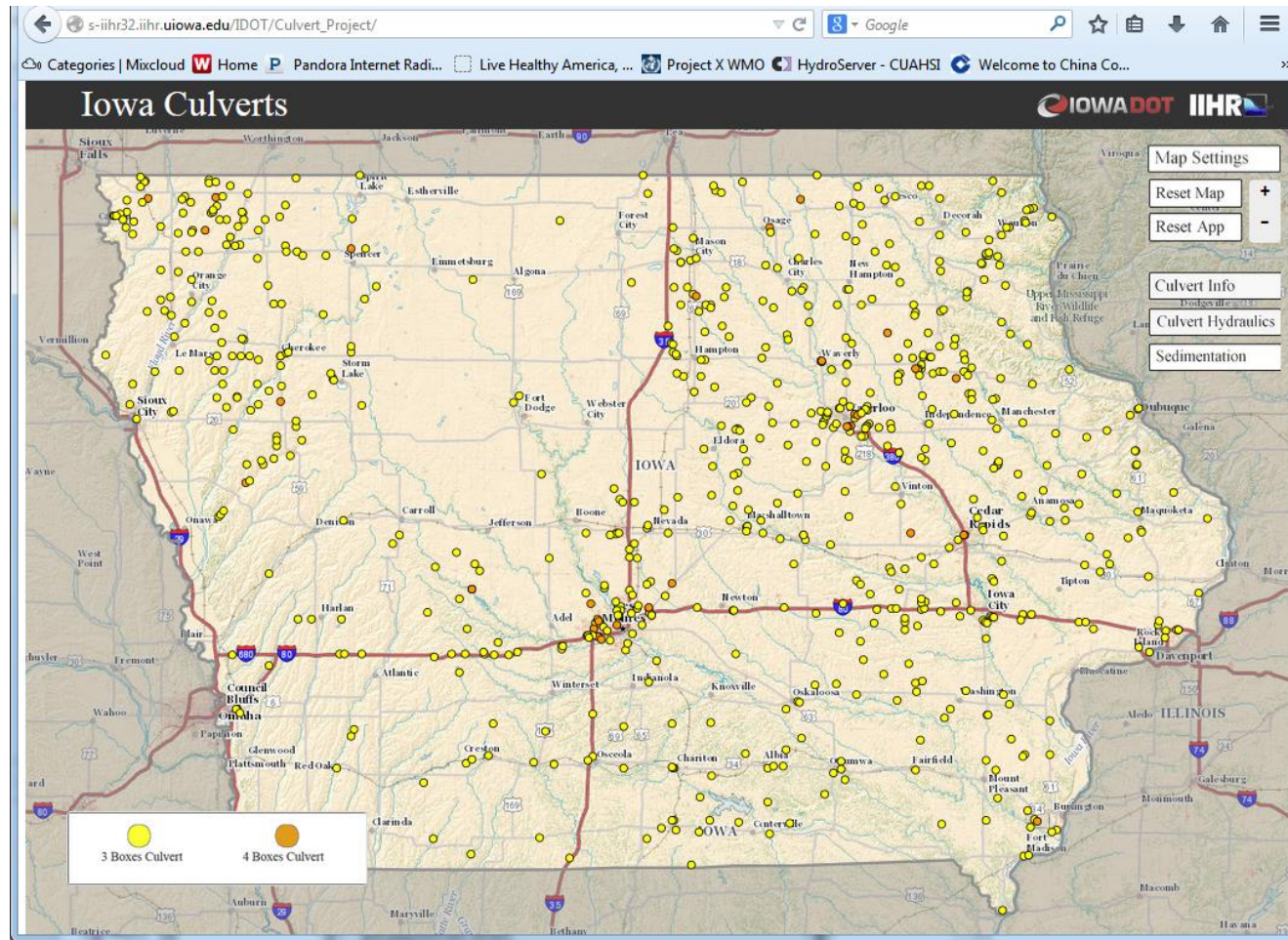
Conclusions

- The fillet-based self-cleaning culvert design proved its reliability and efficiency throughout the testing and monitoring phases
- The design is simple to implement in any stage of the culvert lifetime. For retrofitting, the fillet-based geometry requires less effort because the existing deposited sand in the culvert area can be used to “build” the fillet base.
- Geomats are reliable solutions but grouted “rip-rap” is also feasible (the first solution is more expensive than the second)
- Due to the number and complexity of the factors involved in the sedimentation process and the limited amount of resources available for the study, one culvert geometry and site was thoroughly investigated
- Follow up study: TR-665: Mitigation of Sedimentation at Multi-Cell Box Culverts

TR-665: Mitigation of Sedimentation at Multi-Cell Box Culverts

- Sediment accumulation at culverts is site specific
- Goal of study is to merge culvert hydraulic design with sedimentation estimates that are representative to the site in which the culvert is located
- A geo-portal will be created that allows users to compute flows, perform hydraulic analyses, estimate sedimentation accumulation, mapping of sedimentation deposits and queries of culvert information
- Design of the portal has commenced and transfer to the IDOT is tentatively scheduled to take place late 2015 or early 2016

TR-665: Mitigation of Sedimentation at Multi-Cell Box Culverts





DEVELOPMENT OF SELF-CLEANING BOX CULVERT DESIGNS



Iowa Department
of Transportation



**Research and
Technology Bureau**

A DRIVING FORCE OF INNOVATION

Thank you

Questions?

